region with the SMA member **22**. Either of these piezoelectric coatings may help maintain sufficient traction and reduce slip at the interface.

[0083] The piezoelectric coatings will also have the added benefit of generating a voltage/charge each time the piezoelectric coating is loaded during rotation of the first pulley **38** and the second pulley **40** by the SMA member **22**. The piezoelectric coatings may be in electrical communication with a collector, such as the storage device **36**, to capture the electrical energy generated by the piezoelectric coatings.

[0084] Because the circumference of the heat engine **14** drive pulleys may be significantly less than the length of the SMA member **22**, this loading will occur at the frequency of rotation of the pulleys, which is typically around **5** times greater than that of the SMA member **22** loop. The loading frequency of the piezoelectric or EAP element coatings may be in the range of 2 to 5 hertz.

[0085] This electrical charge is energy that is generated by the piezoelectric coatings at each of the three pulley members in the heat engine **14**. The electrical energy could be added to the energy harvested by the heat engine **14** and communicated to the energy storage device **36**.

[0086] Referring now to FIG. **3**, and with continued reference to FIGS. **1** and **2**, there is shown another heat engine **54**, which may also be incorporated and used with the energy harvesting system **10** shown in FIG. **1**. Features and components shown and described in other figures may be incorporated and used with those shown in FIG. **2**. The heat engine **54** is disposed in heat-exchange communication with a hot region **68** and a cold region **70**. The heat engine **54** includes an SMA member **62** traveling a continuous loop around a first pulley **78**, a second pulley **80**, and an idler pulley **82**.

[0087] A first timing pulley **79** and a second timing pulley **81** are mechanically coupled by a timing chain **83**. Inclusion of the mechanical coupling provided by the timing chain **83** (in addition to the SMA member **62**) between the first pulley **78** and the second pulley **80**, means that the heat engine **54** may also be referred to as a synchronized heat engine.

[0088] Unlike the heat engine **14** shown in FIG. **2**, in the heat engine **54** of FIG. **3**, the first timing pulley **79** and the second timing pulley **81** are substantially equal in diameter. In one configuration, the first and second timing pulleys **79**, **81** may be the respective axles of the first and second pulleys **78**, **80**. In the heat engine **54**, the second pulley **80** has a larger diameter than the first pulley **78**.

[0089] As shown in the heat engine **54** of FIG. **3**, when the SMA member **62** contracts after being heated by the hot region **58**, the second pulley **80** creates a larger moment arm than the first pulley **78**. However, the first timing pulley **79** and the second timing pulley **81** provide equal reaction torque. Therefore, the contraction of the SMA member **62** between the first pulley **78** and the second pulley **80** causes the SMA member **62** to again move toward the first pulley **78**. As the heat engine **54** enters dynamic operation, the SMA member **62**, the first pulley **78**, and the second pulley **80** rotate counterclockwise (as viewed in FIG. **3**).

[0090] Referring now to FIG. **4**, and with continued reference to FIGS. **1-3**, there is shown a schematic graphical representation of a work diagram **90**. An x-axis **91** of the work diagram **90** shows the length of the SMA member **22** shown in FIG. **2**, the SMA member **72** shown in FIG. **3**, or another SMA working member incorporated into a heat engine, such as the heat engine **14** or the heat engine **54**. A y-axis **92** of the work diagram **90** shows the tension force of the SMA member **22** shown in FIG. **2**, the SMA member **72** shown in FIG. **3**, or another SMA working member.

[0091] The work diagram **90** shows a work path **94** following a location or region of the SMA member **22** or the SMA member **72** as it loops during operation of the heat engine **14** or the heat engine **54**. Application of a force over a displacement (i.e., a change in length) requires work to be done. A net work zone **96** represents the net work created by the SMA member **22** or the SMA member **72** on each loop. Therefore, the fact that the net work zone **96** is greater than zero shows that the SMA member **22** or the SMA member **72** is producing mechanical work from the thermal energy available to the heat engine **14** or the heat engine **54**.

[0092] Referring again to FIG. **2**, the heat engine **14**—and the energy harvesting system **10**, as a whole—seeks to capture as much of the available thermal energy as possible and convert that thermal energy into mechanical energy, which may then be used to perform other tasks requiring energy. The heat engine **14** may capture all available heat through various recovery methods to improve the overall efficiency of the energy harvesting system **10**.

[0093] The heat engine **54** shown in FIG. **3** includes some, or all, of the same goals and alteration, modification, or optimization techniques. Other heat engines may also incorporate the many of the features described herein. However, for simplicity, much of the discussion herein is illustrated with respect to the heat engine **14**.

[0094] The SMA member **22** is the working element (or driver) for the heat engine **14**, and various alternative designs, modifications, and improvements of the SMA member **22** may be used to improve the efficiency of the heat engine **14**. Without the dimensional changes provided by the SMA member **22**, the heat engine **14** is not able to produce mechanical energy from the thermal energy available. Geometric, material, and manufacturing considerations contribute to the effectiveness of the SMA member **22** in the heat engine **14** or in other heat engines.

[0095] The alloy forming the SMA member **22** may be specifically matched to the operating environment (the first and second temperatures) of the hot region **18** and the cold region **20**. Furthermore, because the waste heat constituting the hot region **18** may come in fluid form (e.g., geothermal or vehicle radiator), convection (e.g., from a drying oven), conduction (e.g., the surface of a vehicle exhaust pipe), or radiation (e.g., solar), the heat engine **14** and the SMA member **22** may be matched to the specific type of waste heat for which the heat engine **14** is planned.

[0096] Matching the alloy to a specific operating environment may reduce or narrow the hysteresis experienced by the SMA member **22** as it loops through the heat engine **14** and continuously contracts and expands under the influence of the hot region **18** and the cold region **20**. The temperature hysteresis—or path dependency—of the SMA member **22** may be reduced by adding, for example, copper to alloys of Nickel and Titanium. In embodiments or configurations where the SMA member **22** includes multiple strands or SMA elements (such as multiple springs), different individual alloys may be used to build the SMA member **22**, such that the heat engine **14** is built to simultaneously operate over a broad range of operating temperatures.

[0097] The SMA member **22** may be formed from thin, straight SMA wire, on the order of, for example, 0.05-0.3 millimeter. Thin-wire may be a relatively inexpensive form of SMA to produce, and produces good operating properties